

D7. Frequency Vibrato as a Factor in the Loudness and Quality of Musical Tones. PAUL B. ONCLEY, *Westminster Choir College, Princeton, New Jersey*.—The importance of the vibrato in musical tones has been emphasized in many studies by Seashore and others. This paper demonstrates theoretically the intricate overtone structure produced by the frequency modulation of a complex wave, and endeavors to explain the subjectively observed dependence of loudness and quality on such modulation. Some conjectural points are raised regarding certain musical devices such as "tone clusters," "chorus effect," etc.

D8. A Search for Non-Auditory Factors Correlated with Masked Auditory Thresholds. A. PEPINSKY AND R. S. GALES, *U. S. Navy Electronics Laboratory, San Diego, California*.—The individual differences in noise-masked thresholds reported by Webster, Lichtenstein and Gales¹ indicated the presence of certain non-auditory factors. A further search for such factors was undertaken. This was made a part of a pilot study, designed to provide information concerning tests promising usefulness in predicting the efficiency of candidates selected for training as operators of electronic detection equipment. A heterogeneous group of 56 college students were given a large battery of intelligence, vocational interest, and personality tests which have to date provided 127 different scores for each of the subjects. Pure-tone audiograms and masked thresholds were also obtained. Each subject then stood a 3-hr. listening watch, divided into four parts by 10-min. rest periods, reporting on hearing 800 cycle tone signals of 1-sec. duration introduced at various intensities, both above and below threshold into a background of white noise. The subject was harnessed and connected by electrodes to provide ten synchronized channels of bio-potential information, including EEG, PGR, superorbital muscle spikes, sphygmomanometer, cardio- and pneumograph during the entire listening watch. An analysis of variance of the scores obtained on efficiency of detection as well as selected concomitant data indicated that the origi-

nally obtained masked threshold values accounted for only five percent of the total variation between individuals whereas a number of the personality factors did quite as well or better. The factor of social extro-introversion was especially significant in that it explained more than 10 percent of the total variation. However, only 25 percent of the total variation is as yet explained. Simple correlation technique promises that much of it will be recovered from the information given by the biopotential data and the projective tests of personality given in the battery of tests. Interesting effects of learning and fatigue were observed as well as indications of subliminal response.

¹ Webster, Lichtenstein, and Gales, *J. Acous. Soc. Am.* **22**, 483 (1950)

SD9. Brownian Motion and the Sense of Hearing. HL. DE VRIES, *University of Groningen, Netherlands*.—The great sensitivity of sense organs leads to a consideration of the possible interference effects caused by Brownian motion in the sensory cells.¹ The weakest audible stimulus involves energies of the order of 10^{-11} ergs or about $250 kT$. Assuming, on the basis of v. Békésy's data, this minimum audible energy to be distributed over 1000 sensory cells, the threshold of a sensitive cell would lie in the neighborhood of $0.25 kT$. Since the average thermal energy per molecule is $1.5 kT$, such a threshold value would imply continuous excitation. The auditory nervous system would thus be unavailable for acoustic stimuli. Therefore a mechanism must be postulated which would concentrate the acoustic energy on a small number of sensory cells: if for example, the mechanical energy were to be transformed into electrical energy, the cells of the smallest electrical resistance would be the most effectively stimulated.² This working hypothesis provides a useful viewpoint for a discussion of such phenomena as cochlear microphonics, phase relations between stimulus and electrical responses from the vestibular system, and the electrophonic effect.

¹ H. de Vries, "Minimum perceptible energy and Brownian motion in sensory processes," *Nature* (London) **161**, 63 (1948).

² H. de Vries, "Brownian movement and hearing," *Physica* **14**, 48-60 (1948).

Psychoacoustics and Speech Communication

Invited Paper

E1. Modern Status of Auditory Theory. ERNEST G. WEVER, *Princeton University, Princeton, New Jersey*.

Contributed Papers

E2. A Duplex Theory of Pitch Perception. J. C. R. LICKLIDER, *Acoustics Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts*.—In the theories of pitch perception now widely supported, pitch is regarded as a unitary attribute of auditory experience. There is good evidence, however, that there are actually two pitch-like attributes, and it is reasonable to suppose that the duplexity of pitch is a reflection of duplexity in the auditory process. The first step in the process is analysis in frequency, performed by the cochlea, which distributes stimulus components of various frequencies to spatially separated channels. The second step, according to the scheme postulated here, is autocorrelational analysis, performed by the neural part of the auditory system, of the signal in each frequency channel. The basic operations of autocorrelational analysis are delay, multiplication, and integration. The nervous system is nicely set up to perform these operations. A chain of neurons makes an excellent delay line. The spatial aspect of synaptic summation provides something very close to multiplication. And the temporal aspect of

synaptic summation is essentially running integration. The duplex theory suggests, therefore, that neural circuits following the autocorrelation model supplement the cochlear frequency analysis. The postulated neural autocorrelator of course does not compute autocorrelation functions of the acoustic stimulus: it operates upon afferent neural signals. Because the markedly non-linear process of neural excitation intervenes between the stimulus and the autocorrelation, the latter gives rise in certain instances to pitches that are not readily explained if the relatively linear cochlear analysis is considered to be the only one. "The case of the missing fundamental" and Schouten's residue effect, for example, are readily accounted for by the duplex theory. In addition, the theory provides a rational basis for the octave relation and for the consonance of other simple harmonic relations.

E3. The Neural Components of the Round Window Response to Pure Tones. WALTER A. ROSENBLITH AND MARK R. ROSENZWEIG, *Psychoacoustic Laboratory, Harvard University, Cambridge, Massachusetts*.—Recent work on the electric potentials recorded from the cochlea in response to click stimuli has emphasized the importance of the so-called neural components (action potentials) of this response. During recent years Galambos and Davis,¹ Wever,² and Davis and his collaborators³ have been concerned with the relation between microphonic and neural potentials for pure tones. This relation